A UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

NBS TECHNICAL NOTE 766

A Gamma Ray Moments Computer Code, GAMMØM–I

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A Gamma Ray Moments Computer Code, GAMMØM–I

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Issued April 1973

National Bureau of Standards Technical Note 766
Nat. Bur. Stand. (U.S.), Tech. Note 766, 41 pages (Apr. 1973)
CODEN: NBTNAE

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.
Price $0.75 domestic postpaid or $0.50 G.P.O. Bookstore.

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A Gamma Ray Moments Computer Code, GAMMØM-I*

Charles M. Eisenhauer, George L. Simmons,†
and Lewis V. Spencer

In this paper we describe a computer code for generating spatial-angular moments of gamma ray energy fluence in an infinite medium. The equation for moments of the energy fluence is given and the techniques used for the solution are discussed. The structure of the code and of the main subroutines is also given. Details of the input and output data are presented and the printout from a sample problem is included.

Key words: Computer code; gamma rays; gamma ray transport; gauss quadrature; moments; shielding.

I. Introduction

In this note we describe a computer program to calculate spatial and angular moments of the gamma ray fluence in an infinite medium. These moments can then be used to reconstruct spatial and angular distributions by techniques described elsewhere [1,2][1].

Application of the method of moments to problems in gamma ray attenuation was first discussed by Spencer and Fano [3]. Later Goldstein and Wilkins of Nuclear Development Associates collaborated with Spencer to produce a systematic tabulation of buildup factors for gamma radiation [4]. That reference also contains an excellent discussion of the solution of the transport equation by the moments method. The data published in that report have stood for almost twenty years as the main source of information on penetration of gamma rays from point isotropic sources.

Although the data of reference [4] are sufficiently accurate for many practical applications, they have certain limitations:

1. Tabulations were restricted to energies between 0.255 and 10 MeV.
2. Tabulations were limited to depths of less than 20 mean free paths of the source radiation.

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[1] Figures in brackets indicate the literature references at the end of this paper.

3. Results did not include the effects of annihilation or fluorescent radiation.
4. Data are available for only about six elements and water.
5. Calculations were limited to sources whose angular distribution is azimuthally symmetric with respect to a direction perpendicular to the plane of a slab.
6. The data were generated on an early computer, the SEAC, which quickly became obsolete.

An effort is in progress at the National Bureau of Standards to produce gamma ray data which are not subject to these restrictions.

The first major production of moments data at NBS was accomplished by a computer program written by Spencer and Lamkin [5] for the IBM 704 machine. Several reports [6,7,8] give penetration data generated by this program in water and concrete media. The main application of these results, however, appeared in an NBS Monograph [9] on the calculation of shielding from fallout gamma radiation. The data in this Monograph form the technical basis for the Standard Method [10,11,12,13] used by the Defense Civil Preparedness Agency (formerly Office of Civil Defense) to evaluate the protective capability of structures. This computer program extended the range of source energies down to about .020 MeV in energy but had the disadvantage that it was written in machine language.

Accordingly, a gamma ray moments code written in FORTRAN IV language was developed with the intent of eliminating all the restrictions listed earlier. This code, called GAMMØM-I, is the subject of this report.

II. Theory

A. Moments Equations

In order to make this report self-contained we sketch the development of the moments equations for gamma rays. The derivation of the moments equation for gamma rays given here is very similar to that described in the documentation of MOMENT-I, a neutron moments code [14]. The main difference between the two codes is that it is convenient in the neutron moments code to solve for the collision density moments

$$\Psi_{n\ell}(E) = \sigma(E)\, \phi_{n\ell}(E) \quad , \quad \text{(neutrons)}$$

where $\Sigma(E)$ is the total cross section and $\phi_{n\ell}(E)$ are moments of the neutron fluence; whereas in the gamma ray code the quantity solved for is the energy fluence,

$$I_{n\ell}(E) = E\phi_{n\ell}(E) \quad \text{(gammas)}$$

where E is the gamma ray energy in units of the rest energy of the electron (mc^2 units) and $\phi_{n\ell}(E)$ are moments of the gamma ray fluence.

The gamma ray transport equation in one dimensional plane geometry, including fluorescent and annihilation radiation, has the form

$$\cos\theta\frac{\partial\Phi}{\partial z}(E,z,\vec{\omega}) + \mu(E)\Phi(E,z,\vec{\omega}) = \int_{E}^{\infty} dE' \int_{4\pi} d\vec{\Omega}'\, K(E'\to E,\vec{\omega}'\to\vec{\omega})\Phi(E',z,\vec{\omega}) + \sum_i \delta(E-E_i)Y_i \int_{E_i'}^{\infty} \mu_i(E')\Phi(E',z,\vec{\omega})dE' + S(E,z,\vec{\omega}). \tag{1}$$

where

$\Phi(E,z,\vec{\omega})$	is the gamma ray fluence (photons/(cm^2-ster-mc^2 unit)),
$\mu(E)$	is the total cross section (Thomson units per electron),
$\vec{\omega}$	is a unit vector in the photon direction, $\vec{k}$ is a unit vector along the positive z axis, and $\vec{\omega}\cdot\vec{k} = \cos\theta$,
$S(E,z,\vec{\omega})$	is the source strength (photons/(cm^{-3}-ster-mc^2 unit)),
$K(E'\to E,\vec{\omega}'\to\vec{\omega})$	is the Klein Nishina scattering probability per unit path length (TU/electron/mc^2 unit)
E_i	is the energy of either a fluorescent photon or an annihilation photon
$\mu_i(E)$	is the cross section for either photoelectric absorption or pair production (TU/electron)
Y_i	is the yield of either fluorescent photons or annihilation photons, and
E_i'	is the threshold for photoelectric absorption or pair production (mc^2 units)

The source term for fluorescent and annihilation radiation may include any process in which photons above a threshold energy E_i are absorbed according to a cross section μ_i, with the subsequent emission of photons at energy E_i. The calculations reported in reference [4] treated these processes as pure absorption (i.e. $Y_i = 0$).

Following the usual practice we find it more convenient to study the energy fluence rather than the number fluence. We therefore let

$$I(E,z,\vec{\omega}) = E\phi(E,z,\omega) \tag{2}$$

The transport equation (1) then becomes

$$\cos\theta \frac{\partial I}{\partial z}(E,z,\vec{\omega}) + \mu(E)I(E,z,\omega) = \int_E^\infty dE' \int_{4\pi} d\Omega' K(E'\to E,\vec{\omega}'\to\vec{\omega})I(E',z,\vec{\omega})$$
$$+\sum_i E_i\delta(E-E_i)Y_i\int \frac{\mu_i(E')I(E',z,\vec{\omega})}{E'}dE' + ES(E,z,\vec{\omega}) \tag{3}$$

Contrary to earlier procedure, however, we use as an independent variable the energy rather than the wavelength λ of the photon.

If one now expands the energy flux in spherical harmonics,

$$I(E,z,\vec{\omega}) = \sum_{\ell=0}^{\infty}\sum_{m=-\ell}^{\ell}\sqrt{\frac{2\ell+1}{4\pi}}\, I_\ell^m(E,z)\, Y_\ell^m(\theta,\varphi) \tag{4}$$

and defines spatial moments of the angular expansion coefficients as

$$I_{n\ell}^m(E) = \frac{\mu_o^{n+1}}{n!}\int_{-\infty}^{\infty} z^n\, I_\ell^m(E,z)dz, \tag{5}$$

the transport equation becomes a function of energy alone. However, there is an infinite set of equations for $I_{n\ell}^m(E)$. Here, μ_o is the total cross section at the source energy. The source term can be obtained by evaluating

$$S_{n\ell}^m(E) = \frac{\mu_o^{n+1}}{n!}\int_{-\infty}^{\infty} z^n dz \int_{4\pi}\sqrt{\frac{4\pi}{2\ell+1}}\, Y_\ell^{m*}(\theta,\varphi)ES(E,z,\vec{\omega})\, d\vec{\Omega} , \tag{6}$$

where Y_ℓ^{m*} is the complex conjugate of Y_ℓ^m. The moments equation then has the form

$$\mu(E)\, I^m_{n\ell}(E) = \int_E^\infty K(E'\to E)\, P_\ell(1-\tfrac{1}{E}+\tfrac{1}{E'})\, I^m_{n\ell}(E')dE' + + \mu_o \frac{\sqrt{(\ell+1)^2-m^2}}{(2\ell+1)}\, I^m_{n-1,1+1}(E) + \mu_o \frac{\sqrt{\ell^2-m^2}}{2\ell+1}\, I^m_{n-1,\ell-1} + + \mu_o \delta_{\ell o} \sum_i \delta(E-E_i)\, Y_i \int_{E_i'}^\infty \mu_i(E') I_{no}(E')\, \frac{dE'}{E'} + S^m_{n\ell}(E) \tag{7}$$

where

$P_\ell(\cos\theta)$ is the Legendre polynomial

and

$$K(E'\to E) = 0.375E \left[\frac{E'}{E} + \frac{E}{E'} - 1 + \cos^2\theta\right]/E'^3 \quad .$$

For a plane source located at $z = 0$, i.e. $S(E,z,\vec{\omega}) = S(E,\cos\theta)\, \delta(z)/4\pi$, equation (7) reduces to

$$\mu(E) I_{n\ell}(E) = \int_E^\infty K(E'\to E) P_\ell(1-\tfrac{1}{E}+\tfrac{1}{E'}) I_{n\ell}(E')dE' + \delta_{\ell o} \sum_k \delta(E-E_k) E_k S^k_n + \frac{(1-\delta_{no})\mu_o}{(2\ell+1)} \left[(\ell+1) I_{n-1,\ell+1}(E) + \ell I_{n-1,\ell-1}(E)\right] + \mu_o E \delta_{no} S_\ell(E) \tag{8}$$

where

$$S_\ell(E) = \int_{-1}^{1} d(\cos\theta) P_\ell(\cos\theta) S(E,\cos\theta) \tag{9}$$

and

$$S^k_n = Y_k \int_{E'_k} \mu'_k(E') I_{no}(E')dE'/E' \quad .$$

The computer code GAMMØM-I is designed to treat monoenergetic sources, that is, sources for which

$$S(E) = \delta(E-E_o) \ . \tag{10}$$

To eliminate the difficulties of the δ-function we express the moments as a sum of a δ-function and a continuous function $I^s_n(E)$:

$$I_{n\ell}(E) = I^s_{n\ell}(E) + S_o E_o \delta(E-E_o) C_{n\ell} + \sum_k \delta(E-E_k) E_k \left(\frac{\mu_o}{\mu_k}\right)^{n+1} C^k_{n\ell} \tag{11}$$

where $C_{n\ell}$ are a set of coefficients that can be generated by recursion:

$$C_{n\ell} = \frac{1}{(2\ell+1)} \left[(\ell+1) C_{n-1,\ell+1} + C_{n-1,\ell-1} \right] \tag{12}$$

with $C_{o\ell} = S_\ell(E)$

and the $C^k_{n\ell}$ are a somewhat more complicated set given by

$$C^k_{n\ell} = \frac{1}{(2\ell+1)} \left[(\ell+1)\, C^k_{n-1,\ell+1} + \ell C^k_{n-1,\ell-1} \right] + \delta_{no} S^k_n \tag{13}$$

The equation that is actually solved in the computer code is therefore:

$$\mu(E) I^s_{n\ell}(E) = \int_E^\infty K(E' \rightarrow E) P_\ell\left(1 - \frac{1}{E} + \frac{1}{E'}\right) I^s_{n\ell}(E') dE' + E_o K(E_o \rightarrow E) P_\ell\left(1 - \frac{1}{E} + \frac{1}{E_o}\right) C_{n\ell}$$

$$+ \delta_{\ell o} \sum_k \delta(E-E_k) E_k S^k_n + \frac{(1-\delta_{no})}{2\ell+1} \mu_o \left[(\ell+1) I_{n-1,\ell+1}(E) + \ell I_{n-1,\ell-1}(E) \right] \tag{14}$$

where S^k_n is given by

$$S^k_n = Y_k \left\{ S_o \mu'_k(E_o) C_{n\ell} + \int_{E'_k}^\infty I^s_{no}(E') \mu'_k(E') \frac{dE'}{E'} \right\} \ .$$

The contributions from the δ-functions, which are associated with the primary and secondary sources, and are given in equation (11), is also calculated by the code.

B. Gaussian Technique Applied to Scattering Integral.

The method used by earlier workers [2,3] to obtain solutions to Equation (14) was to assume a grid of energies (usually with constant intervals of the wavelength in Compton units and proceed with the numerical solution from high to low energies. With this procedure the number of points in the numerical integration of the scattering kernel is restricted to the number of solutions previously obtained. However, the forward peak in the Klein-Nishina scattering distribution makes it desirable to obtain better definition in the region of integration for which $E' \approx E$. To obtain better definition we evaluate the integral in this region by Gaussian Quadrature as in the neutron code.

The application of Gaussian Quadrature to Equation (14) is very similar to the procedure described in Reference [12] for solution of the moments equations for neutrons. Again, to make this report self-contained we reproduce that discussion here.

This technique has the advantage that its accuracy depends only on the smoothness of the energy fluence function $I^{s}_{n}(E')$ in the integrand, rather than on the smoothness of the entire integrand, which is generally more rapidly varying due to the scattering kernel. We rewrite Eq. (14) in the following manner:

$$\begin{aligned}\mu(E)I^{s}_{n\ell}(E) - \int_{E}^{E_i} K(E'\to E)P_\ell\left(1-\frac{1}{E}+\frac{1}{E'}\right)I^{s}_{n\ell}(E')dE' &= \int_{E_i}^{E_o} K(E'\to E)P_\ell\left(1-\frac{1}{E}+\frac{1}{E'}\right)I^{s}_{n\ell}(E')dE' \\ &+ \frac{(1-\delta_{no})\mu_o}{(2\ell+1)}\left[(\ell+1)I^{s}_{n-1,\ell+1}(E) + \ell I^{s}_{n-1,\ell-1}(E)\right] \\ &+ E_o K(E_o\to E)P_\ell\left(1-\frac{1}{E}+\frac{1}{E_o}\right)C_{n\ell} + \delta_{\ell o}\sum_k \delta(E-E_k)E_k S_{nk} \quad . \end{aligned} \tag{15}$$

In this equation E_i is the solution energy just above E. Letting R equal the right hand side of Eq. (15) and noting that

$$\mu(E)I^{s}(E) = \int_{E}^{E_i} \mu(E')I^{s}(E')\,\delta(E'-E)dE' \quad ,$$

we may rewrite Eq. (15),

$$\int_{E}^{E_i} [\mu(E') \, \delta(E'-E) - K(E'\to E) \, P_\ell(1-\tfrac{1}{E} + \tfrac{1}{E'})] I^s_{n\ell}(E') dE' = R \quad . \tag{16}$$

This integral is evaluated using the Gaussian technique by approximating the term in the square brackets by the sum of two delta functions.

$$\mu(E')\delta(E'-E) - K(E'\to E) \, P_\ell(1-\tfrac{1}{E} + \tfrac{1}{E'}) = \alpha_{1\ell}\delta(E'-E_i) + \alpha_{2\ell}\delta(E'-E^*_\ell). \tag{17}$$

Note that the function used in equation (17) could be modified by some function of E′, in order to make the remaining function $I^s_n(E')$ in the integrand of equation (16) more smoothly varying. We have not made any attempt to explore such modifications. Inserting the right hand side of equation (17) into (16) the integral is readily evaluated to give

$$\alpha_{1\ell} I^s_{n\ell}(E_i) + \alpha_{2\ell} I^s_{n\ell}(E^*_\ell) = R \tag{18}$$

The three parameters $\alpha_{1\ell}$, $\alpha_{2\ell}$, and E^*_ℓ are determined by conditions on the first three moments of the scattering kernel:

$$\mu(E)\delta_{jo} - I^\ell_j = \int_0^{E_i-E} (E'-E)^j [\mu(E')\delta(E'-E) - K(E'\to E) P_\ell(\cos\Theta)] d(E'-E) \tag{19}$$

$$= \alpha_{1\ell}(E_i-E)^j + \alpha_{2\ell}(E^*_\ell-E)^j \quad ,$$

$$\text{for } j = 0,1,2 \quad .$$

Solving this system of equations gives

$$E^*_\ell = E + \frac{-I^\ell_1(E_i-E) + I^\ell_2}{I^\ell_1 + (\mu(E)-I^\ell_o)(E_i-E).} \quad ,$$

$$\alpha_{2\ell} = \frac{-I^\ell_1 + (I^\ell_o-\mu(E))(E_i-E)}{E^*_\ell - E_i} \quad , \quad \text{and} \tag{20}$$

$$\alpha_{1\ell} = \mu(E) - I^\ell_o - \alpha_{2\ell} \quad .$$

In this application of the Gaussian technique to the integral in Eq. (16) the argument of one delta-function is not fixed beforehand. This quadrature is exact for any energy fluence function $I_n^s(E')$ which is of degree two or lower in the range between E and E_i.

The energy fluence moments at E^* can be obtained by solving Eq. (12). Generally, E^* is somewhat lower than E and therefore an interpolation must be performed to obtain the value of the moments at E. Also, in evaluating the integral on the righthand side of Eq. (15), an interpolation is performed to obtain $I_n^s(E')$. GAMMØM-I uses linear interpolation for the solution at E and quadratic interpolation to obtain $I_n^s(E')$. Since the energy fluence is slowly varying with energy, these interpolations should introduce little error into the result.

III. Organization and Description of GAMMØM-I

A. General Structure

GAMMØM-I is structured as a five segment overlay. The structure of this overlay is shown in Fig. 1. The function of each segment may be described briefly as follows:

Segment 1.	Reads all input data except dose response coefficients.
Segment 2.	Calculates discontinuity energies and solution mesh parameters.
Segment 3.	Calculates scattering kernel and writes the results on Tape 8.
Segment 4.	This is the main solution part of the program. The Gaussian procedure is used. Also the effect of fluorescence and annihilation is calculated in this segment. Drum storage is required.
Segment 5.	This segment prints the results and calculates dose moments for the response functions that are defined by means of input data. Also the moments are written on tape 9 for later processing.

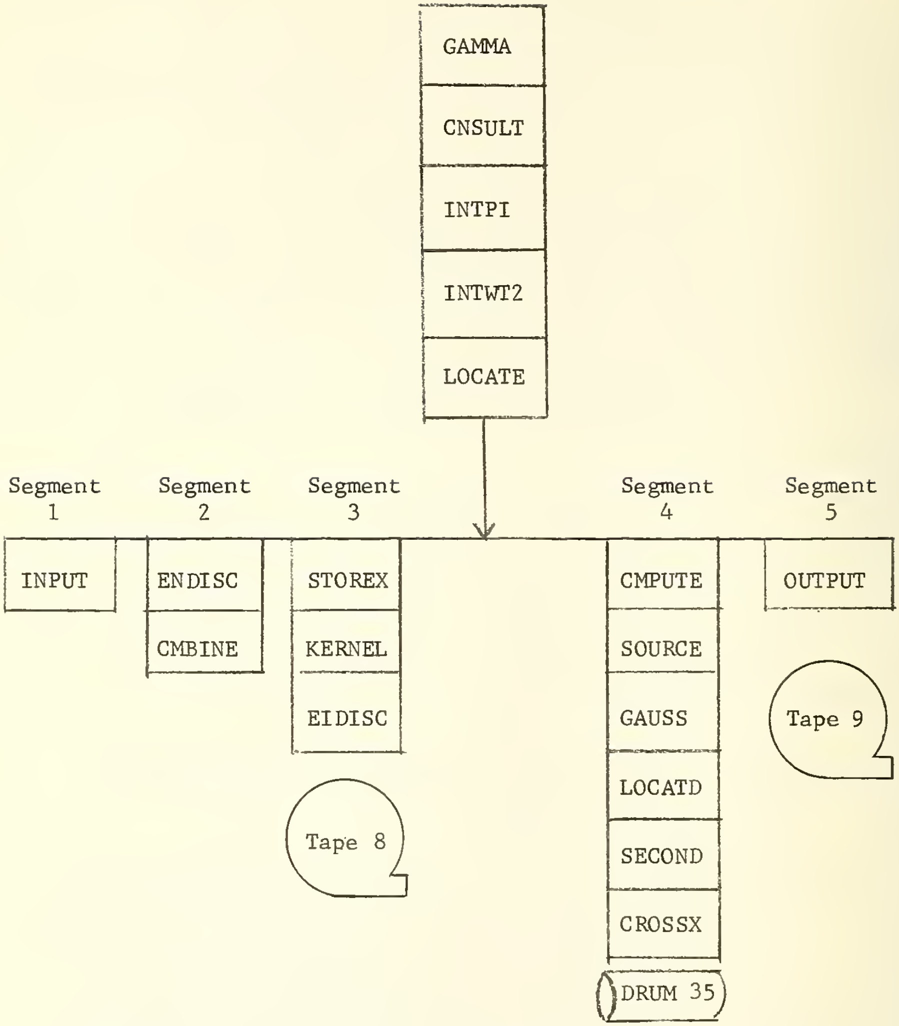

FIGURE 1. Overlay structure for GAMMØM-I computer code

This overlay procedure is employed on the UNIVAC 1108 and should be easy to implement on other computers. Note that the interpolation and integration routines are available to each segment.

B. Discussion of GAMM0M-I Subroutines

GAMMA

This routine calls in the main subroutines in the following sequence:

INPUT - reads in input data related to energy grids, cross sections, and parameters related to the source angular distribution and the linkage between moments.

ENDISC - identifies the energies at which primary source energies exist and anticipates the existence of discontinuities in the scattered energy flux moments due to these sources.

ST0REX - calculates Legendre coefficients of the scattering kernel and stores them on tape.

SEC0ND - calculates the source terms for fluorescent and annihilation radiation both for the continuous spectrum and the discrete lines.

COMPUTE - solves the moments equation numerically for a plane source and a fixed solution energy.

OUTPUT - writes moments on tape for each energy and calculates dose moments for plane and point sources.

INPUT

This subroutine reads in all data related to cross sections, energy grids, source characteristics, and moment linkages. A detailed description of the input data is given in section IV.

ENDISC

This subroutine sets up the energy grid for which solutions are to be calculated. Allowance is made for double-valued solutions at energies for which discontinuities in the scattered energy fluence occur. The fineness of the grid is determined by input parameters except that 70 intervals are automatically assumed below the lowest single-scatter cutoff. The subroutine calls CMBINE which combines energy grids determined for each δ-function source into a final energy grid.

ST0REX

This subroutine interpolates for the total cross section at each energy and writes detailed calculations of the scattering kernel on to tape. It calls EIDISC and KERNEL.

EIDISC - This subroutine sets up the energy grid for each integration over the scattering kernel. The fineness of the grid is determined by the input parameters MAXN0, which sets the minimum number of intervals over any single scatter region and MINN0 which is only used when the problem involves more than one monoenergetic source.

KERNEL - This subroutine calculates the required number of Legendre coefficients of the scattering kernel.

SEC0ND

This subroutine calculates the contribution of the annihilation and fluorescent secondary source radiation to the scattered energy fluence moments. This contribution is analogous to the contribution from single-scatter radiation generated by the primary source. This subroutine also calculates the contribution from photons at the discrete secondary source energies and adds them to the direct radiation from the primary source.

CMPUTE

This subroutine solves equation 14 for moments of the energy fluence Solutions proceed from the highest energy downward with numerical integration of the scattering integral.

OUTPUT

This subroutine contains options to print or write on to tape the energy fluence moments for scattered and direct radiation. Dose moments are produced by integration over the energy fluence moments, for up to ten dose response functions. Dose moments may be printed and/or punched on cards.

IV. Input and Output Description

A. Card Input

The following cards are read in the subroutine INPUT:

Card Type 1 (I1, 12A6)

IPR0B Type of input data

IPR0B = 1 All input data required.

IPR0B = 2 No source data required; source is assumed to be the same as in previous problem.

IPR0B = 3 No cross section or source data required; these data are assumed to be the same as in previous problem.

IPR0B = 4 Only data for source angular distribution is required; all other input data are assumed to be the same as in previous problem.

IPR0B = 5 End of calculation (See card type 22).

TITLE Alpha numeric title for problem.

Card Type 2 (11I5)

NMUS Number of energies for which total cross sections are to be read in.

NS0RS Number of primary source energies.

LS Maximum number of Legendre coefficients calculated by code ($\ell = 0,1,\ldots$ LS-1).

MINN0 The minimum number of intervals in the scattering kernel between the energy ranges of single scattering interactions.

MAXN0 The minimum number of intervals in the scattering kernel for any single scatter interaction.

NPXS Number of partial cross sections such as pair production or photo-electric absorption. NPXS > 0 only if annihilation or fluorescent radiation is to be included in calculation.

I0UT Parameter determining type of output information.

I0UT = 0 Fluence moments printed and written on unit 9. Plane and point dose moments printed. Plane dose moments punched.

I0UT = 1 Fluence moments written on unit 9 and printed only for primary and secondary source energies. Plane and point dose moments printed. Plane dose moments punched.

I0UT = 2 Fluence moments printed. Plane and point dose moments printed.

I0UT = 3 Fluence moments printed only for primary and secondary source energies. Plane and point dose moments printed. Plane dose moments punched.

KEYIND Index which allows part of calculation to be skipped.

KEYIND = 0,1 Do entire calculation.

KEYIND = 2 Compute moments using scattering kernel data stored previously on tape mounted on logical unit 8.

NRN Run number (arbitrary).

IC0NT Obsolete parameter (arbitrary).

NPRINT Number of solution energies for which detailed printout of solution is desired. (For diagnostic use.)

Card Type 3 (3E10.0)

ET0P Highest energy for which solutions are to be calculated. Ordinarily ET0P is equal to the highest primary source energy.

EB0TM Lowest energy for which solutions are to be calculated.

SO Factor necessary to convert energy from input units to mc^2 units. (Normally input energies are in MeV units and S0 = 1.95692).

XO Factor necessary to convert cross section from input units to Thomson units. (Normally input cross sections are cm^2/g units and XO is then $(.400594\ Z/A)^{-1}$.

Card Type 4 (20I5) (Only if NPRINT > 0)

(IXEN(I), I = 1, NPRINT) Indices of solutions for which detailed printout is desired.

Card Type 5 (8E10.0) (Only if IPR0B ≤ 2)

(EMUS(I), TABMU(I), I = 1, NMUS) List of energies and tabulated cross sections.

The next 5 types of cards are required only if fluorescent or annihilation radiation is to be calculated.

Card Type 6 (20I5) (Only if IPR0B ≤ 2 and NPXS > 0)

(NPART(I), I = 1, NPXS) Number of tabulated cross sections for each reaction.

Card Type 7 (8E10.0) (Only if IPR0B ≤ 2 and NPXS > 0)

(YIELD(I), I = 1, NPXS) Yield for each reaction.

Card Type 8 (8E10.0) (Only if IPR0B ≤ 2 and NPXS > 0)

(ECUT(I), I = 1, NPXS) Threshold energy for each reaction.

Card Type 9 (8E10.0) (Only if IPR0B ≤ 2 and NPXS > 0)

(ESTART(I), I = 1, NPXS) δ-function energy of photon produced by each reaction.

Card Type 10 (8E10.0) (Only if IPROB $\le$ 2 and NPXS > 0)

(EPART(I,J), SIGMA(I,J), J = 1, NPART(I)) List of energies and tabulated partial cross sections. (One set for each reaction.)

Card Type 11 (8E10.0) (Only if IPRØB = 1)

(ESØRS(I), STSØRS(I), I = 1, NSØRS) List of energies and strength of each primary source.

Card Type 12 (4I5)

NLØ Number of harmonic coefficients of the source angular distribution.

LZRØ Index of source harmonic when NLØ = 1; otherwise arbitrary.

MZRØ Index of azimuthal harmonic. (MZRØ = 0 unless both source distribution and detector response include azimuthal dependence).

Card Type 13 (4I3, 4(I6, 3I3))

N(I) n-index of the i^{th} moment

L(I) ℓ-index of the i^{th} moment

LINKH(I) i-index of higher-ℓ linkage moment

LINKL(I) i-index of lower-ℓ linkage moment

Card Type 14 (8E10.0)

(CNL(I), I = 1, NLØ) Harmonic coefficients of source angular distribution.

The following cards are read in the Main Program GAMMA:

Card Type 15 (2I5) (Only if KEYIND > 1)

NENSP Number of energies at which solutions are to be obtained.

NED Number of discontinuities in solution mesh.

Card Type 16 (3(I3, IP2E11.6)) (Only if KEYIND > 1)

NEIN(K) number of integration points for K^{th} solution.

ENS(K) energy corresponding to K^{th} solution.

EMUN(K) total cross section corresponding to K^{th} energy (TU/el)

Card Type 17 (3(I3, 1P2E11.6) (Only if KEYIND > 1)

NSW(K) number of solutions, uniformly spaced in lethargy (E_i/E_{i-1} constant) in K^{th} solution interval.

ED(K) highest energy in K^{th} solution interval.

DED(K) ratio of energies of successive solutions in K^{th} interval.

Subroutine OUTPUT

Card Type 18 (2I5)

NDOSE number of energies at which dose response coefficients are tabulated

NOFD number of types of detector responses to be calculated

Card Type 19 (8E10.0)

ECONS factor to convert energies in input units to energy in mc^2 units (see Card Type 3)

(CONS(I), I = 1, NOFD) factor to convert energy absorption coefficients from input units to units of TU/electron. (see Card Type 3)

Card Type 20 (8E10.0)

(EDOSE(I), I = 1, NDOSE) energy list for dose response coefficients.

Card Type 21 (8E10.0)

(SIGMAD(I,J), I = 1, NDOSE) energy absorption coefficient for I^{th} energy and J^{th} type of dose response

Card Type 22 (blank)

End of calculation

B. Scattering Kernel Tape

For the UNIVAC 1107/1108 systems, the results of the calculations of the scattering kernel are written tape unit 8. This tape must be available for all values of KEYIND. The tape is written in the binary mode. Binary records are written in the following form for each solution:

Record 1

WRITE (8) ENS(N), NIN, LSP, ND

where ENS(N) is energy for the N^{th} solution

NIN is the number of integration points in the integrand

LSP is the number of Legendre coefficients LS, plus 4

ND is the number of intervals over which the integration mesh is uniformly spaced.

Record 2

WRITE (8) (NKIND(K), K = 1, NIN)

where NKIND(K) is an index which indicates when the integration mesh changes

NKIND > 0: number of energies with constant integration mesh

NKIND = 0: no change in integration mesh

Record 3

WRITE (8) (EIN(K), K = 1, NIN)

where EIN(K) is the list of energies in the integrand

Record 4

WRITE (8) (EDI(K), K = 1, ND)

where EDI(K) is the list of energies at which the integration mesh changes

Record 5

WRITE (8) ((XKIN(K,L), L = 1, LS), K = 1, NIN)

where XKIN(K,L) is the $(L-1)^{th}$ harmonic coefficient of the cross section for the K^{th} energy in the integrand

C. Moments Solution Tape

For the UNIVAC 1107/1108 systems, moments are written on tape unit 9. This tape must be available for IOUT (input card 2) values less than 2. The following describes the BCD records written for a single problem.

Record 1 (12A6)

TITLE Problem title

Record 2 (5I5)

NENS number of solution energies

NSORS number of primary source energies

NOFD number of different detector responses

NNL number of (n,ℓ) combinations

NDOSE number of energies at which dose response coefficients are tabulated

Record 3 (16I5)

(N(I), L(I), I = 1, NNL) n and ℓ indices of each solution

Record 4 (1P10E13.7)

(ENS(I), I = 1, NENS) energy list

Record 5 (1P10E13.7)

(EMUN(I), I = 1, NENS) list of total cross sections

Record 6 (1P10E13.7)

(CNL(I), I = 1, NNL) list of $C_{n\ell}$ values for each (n,ℓ) combination

Record 7 thru 2*NNL + 6 (1P10E13.7)

(SOLN (NENS + K, I), K = 1, (NSORS + NPXS)) Direct radiation moments for primary and secondary sources for the I^{th} (n,ℓ) combination

(SOLN(K,I), K = 1, NENS) Scattered radiation moments for the Ith (n,ℓ) combination.

D. Discussion of Output Data

The data preceded by (NPRINT > 0) are printed only for those solutions for which detailed printout is requested. These solutions are chosen by means of the input parameters NPRINT and IXEN. These data are for diagnostic use.

The printout consists of the following blocks of data:

Input data from INPUT subroutine.

Tabulation of energies and total cross sections in input units.

Tabulation of energies and total cross sections in units of electron mass and Thomson units, respectively.

(NPXS > 0) List of secondary source energy, threshold energy yield number of tabulated partial cross sections, list of energies and cross sections for each partial interaction.

List of source energies (primary and secondary) and source strengths (strength of secondary sources is initially set at zero).

List of normalized source energy and strength.

List of indices for each moment and values of linkage coefficients.

List of solution index, number of integration points, energy, and total cross section for each solution.

List of index numbers of solution points, energy and ratio of successive solution energies associated with each discontinuity.

Discontinuity refers to an energy below which the solution energy grid changes.

(NPXS > 0) List of moment (n,ℓ) indices and contribution from integration over scattered moments.

Energy and partial cross section for each primary scource.

List of moment (n,ℓ) indices and contribution from scattered moments and primary sources.

List of moment (n,ℓ) indices and contribution from scattered moments and primary sources, weighted by radiation yield and appropriate cross section ratios.

List of energies for which secondary sources may contribute to scattered moments. (Note that the SOURCE subroutine calculates a non-zero contribution only when

$$\frac{E_2}{(2E_2 + 1)} < E < E_2 ,$$

where E_2 is the energy of the secondary source.

(I = IXEN(J)) The following information is printed only for those energies for which detailed printout has been requested.

- (n,ℓ) index, source contribution, and source contribution at solution discontinuity.
- Parameters associated with this solution energy.
- Index of solution, number of integration points, integrand energy.
- Legendre coefficients of the scattering cross section, for each interval of integration.
- ℓ index, three Gauss parameters and three obsolete parameters, for each ℓ-value.
- Energy and contribution from numerical integration for each (n,ℓ) combination
- Energy and moment solution for each (n,ℓ) combination.

Printout of input parameters.

List of energies and dose response coefficients.

List of energies in mc^2 units and dose response coefficients in Thomson units per electron.

(IOUT = 0 or 2) Energy, total cross section, solution index, LZRO, and MZRO, followed by a list of (n,ℓ) indices and fluence values for each (n,ℓ) combination.

Energy, total cross sections, solution index, LZRO and MZRO, followed by (n,ℓ) indices and fluence values for source energies only.

List of energy, interpolated dose response coefficient (normalized) fluence (0,0) moment, cumulative dose integral for each type of response.

Normalizing constant for which total energy absorbed (i.e. the zero-zero moment for total dose) is equal to unity. The deviation of the moment from unity is a measure of inconsistency in cross sections introduced by interpolation procedures in the code.

Title of calculation and index of dose response coefficient.

Dose moments for a plane isotropic (PLI) source. Values are given for total, direct (including secondary sources) and scattered dose.

Dose moments for a point isotropic(PTI) source. Values are given for total, direct (including secondary sources), and scattered dose.

V. Sample Problem.

```
$KK
NMUS     =            +33,
NSORS    =             +1,
LS       =            +21,
MINNO    =            +10,
MAXNO    =            +40,
NPXS     =             +1,
1OUT     =             +1,
KEY1ND   =             +1,
NRN      =          +6012,
ICONT    =             +0,
NPRINT   =             +0,
ETOP     =     .12500000E+01,
EBOTM    =     .15000000E-01,
S0       =     .19569242E+01,
X0       =     .49899000E+01,
$END

 TOTAL CROSS SECTIONS  ENERGY--SIGMA
 1.0000+02  2.3540-02  8.0000+01  2.2930-02  6.0000+01  2.2190-02  5.0000+01  2.1800-02  4.0000+01  2.1340-02  3.0000+01  2.0990-02
 2.0000+01  2.0980-02  1.5000+01  2.1470-02  1.0000+01  2.3070-02  8.0000+00  2.4490-02  6.0000+00  2.6980-02  5.0000+00  2.8970-02
 4.0000+00  3.1900-02  3.0000+00  3.6530-02  2.0000+00  4.4800-02  1.5000+00  5.1920-02  1.0000+00  6.3720-02  8.0000-01  7.0900-02
 6.0000-01  8.0740-02  5.0000-01  8.7330-02  4.0000-01  9.5760-02  3.0000-01  1.0730-01  2.0000-01  1.2500-01  1.5000-01  1.3990-01
 1.0000-01  1.7040-01  8.0000-02  2.0040-01  6.0000-02  2.7340-01  5.0000-02  3.6080-01  4.0000-02  5.5880-01  3.0000-02  1.1180+00
 2.0000-02  3.4450+00  1.5000-02  8.0100+00  1.0000-02  2.6460+01

 TOTAL CROSS SECTIONS  ENERGY--SIGMA
 1.9569+02  1.1746-01  1.5655+02  1.1442-01  1.1742+02  1.1073-01  9.7846+01  1.0878-01  7.8277+01  1.0648-01  5.8708+01  1.0474-01
 3.9138+01  1.0469-01  2.9354+01  1.0713-01  1.9569+01  1.1512-01  1.5655+01  1.2220-01  1.1742+01  1.3463-01  9.7846+00  1.4456-01
 7.8277+00  1.5918-01  5.8708+00  1.8228-01  3.9138+00  2.2355-01  2.9354+00  2.5908-01  1.9569+00  3.1796-01  1.5655+00  3.5378-01
 1.1742+00  4.0286-01  9.7846-01  4.3577-01  7.8277-01  4.7783-01  5.8708-01  5.3542-01  3.9138-01  6.2374-01  2.9354-01  6.9809-01
 1.9569-01  8.5028-01  1.5655-01  9.9998-01  1.1742-01  1.3642+00  9.7846-02  1.8004+00  7.8277-02  2.7884+00  5.8708-02  5.5787+00
 3.9138-02  1.7190+01  2.9354-02  3.9969+01  1.9569-02  1.3203+02

   ESTART  E-CUT OFF     YIELD     NUMBER--ENERGY**SIGMA
  .511006  1.022012  2.000000          17  1.0000+02  2.1050-02  8.0000+01  1.9920-02  6.0000+01  1.8380-02  5.0000+01  1.7370-02
                                           4.0000+01  1.6040-02  3.0000+01  1.4320-02  2.0000+01  1.1830-02  1.5000+01  1.0067-02
                                           1.0000+01  7.6580-03  8.0000+00  6.3890-03  6.0000+00  4.8510-03  5.0000+00  3.9370-03
                                           4.0000+00  2.9190-03  3.0000+00  1.7860-03  2.0000+00  6.2200-04  1.5000+00  1.5800-04
                                           1.0200+00  1.0000-08

  SOURCE ENERGIES ***  ENERGY - STRENGTH
 1.2500+00  1.0000+00  1.0000+00  0.0000

  SOURCE ENERGIES ***  ENERGY - STRENGTH
 2.4462+00  2.4462+00  1.0000+00  0.0000
```

```
INDEX     LINKH     LINKL       N       L    CH              CL              CNL
    1         0         0       0       0 0.00000000    0.00000000     1.00000000+00
    2         0         1       1       1 0.00000000    3.33333332-01 3.33333332-01
    3         2         0       2       0 1.00000000+00 0.00000000     3.33333332-01
    4         0         2       2       2 0.00000000    3.99999999-01 1.33333331-01
    5         4         3       3       1 6.66666664-01 3.33333332-01 1.99999996-01
    6         0         4       3       3 0.00000000    4.28571425-01 5.71428556-02
    7         5         0       4       0 1.00000000+00 0.00000000     1.99999996-01
    8         6         5       4       2 5.99999994-01 3.99999999-01 1.14285710-01
    9         8         7       5       1 6.66666664-01 3.33333332-01 1.42857136-01
   10         9         0       6       0 1.00000000+00 0.00000000     1.42857136-01
```

```
** SOLUTION LISTS **  INDEX-INTERPOLATIONS-ENERGY-SIGMA
  1    1  2.4461552+00  2.8419342-01    2   11  2.3441465+00  2.9074326-01    3   22  2.2463917+00  2.9701971-01
  4   22  2.1527135+00  3.0338509-01    5   22  2.0629418+00  3.0983931-01    6   22  1.9769138+00  3.1638226-01
  7   22  1.8944732+00  3.2301378-01    8   22  1.8154706+00  3.2973367-01    9   22  1.7397625+00  3.3658352-01
 10   22  1.6672115+00  3.4347222-01   11   22  1.5976861+00  3.5043535-01   12   22  1.5310599+00  3.5747176-01
 13   23  1.4672122+00  3.6458022-01   14   24  1.4060270+00  3.7175945-01   15   25  1.3473934+00  3.7895530-01
 16   26  1.2912049+00  3.8627699-01   17   27  1.2373595+00  3.9367501-01   18   28  1.1857596+00  4.0114836-01
 19   29  1.1363115+00  4.0869598-01   20   30  1.0889254+00  4.1631674-01   21   31  1.0435155+00  4.2400064-01
 22   32  9.9999915-01  4.3176876-01   23    0  9.9999922-01  4.3176875-01   24   33  9.7371066-01  4.3666473-01
 25   44  9.4811319-01  4.4158938-01   26   44  9.2318864-01  4.4654240-01   27   44  8.9891932-01  4.5152353-01
 28   44  8.7528801-01  4.5653245-01   29   44  8.5227793-01  4.6152180-01   30   44  8.2987275-01  4.6659349-01
 31   44  8.0805657-01  4.7169803-01   32   44  7.8681391-01  4.7683530-01   33   44  7.6612969-01  4.8200516-01
 34   44  7.4598923-01  4.8720744-01   35   44  7.2637822-01  4.9244199-01   36   44  7.0728277-01  4.9770866-01
 37   44  6.8868931-01  5.0300726-01   38   44  6.7058465-01  5.0826632-01   39   44  6.5295593-01  5.1363203-01
 40   44  6.3579064-01  5.1903422-01   41   45  6.1907660-01  5.2447290-01   42   45  6.0280196-01  5.2994798-01
 43   46  5.8695515-01  5.3545944-01   44   47  5.7152493-01  5.4100724-01   45   47  5.5650035-01  5.4659129-01
 46   48  5.4187074-01  5.5221156-01   47   48  5.2762573-01  5.5786795-01   48   49  5.1375520-01  5.6356043-01
 49   50  5.0024930-01  5.6928889-01   50   50  4.8709846-01  5.7505327-01   51   51  4.7429333-01  5.7969241-01
 52   51  4.6182483-01  5.8555311-01   53   52  4.4968411-01  5.9149109-01   54   53  4.3786256-01  5.9750750-01
 55   53  4.2635177-01  6.0360350-01   56   54  4.1514359-01  6.0978028-01   57    0  4.1514364-01  6.0978025-01
 58   54  4.0613126-01  6.1493067-01   59   64  3.9731452-01  6.2013743-01   60   63  3.8868919-01  6.2540121-01
 61   62  3.8025110-01  6.3072272-01   62   61  3.7199620-01  6.3610267-01   63   62  3.6392051-01  6.4154179-01
 64   63  3.5602013-01  6.4704080-01   65   64  3.4829126-01  6.5260044-01   66   65  3.4073017-01  6.5822149-01
 67   56  3.3333323-01  6.6234121-01   68    0  3.3333325-01  6.6234120-01   69   54  3.2211909-01  6.7148656-01
 70   63  3.1128221-01  6.8097664-01   71   60  3.0080991-01  6.9082246-01   72   59  2.9068993-01  7.0103554-01
 73   57  2.8091040-01  7.1162789-01   74   55  2.7145988-01  7.2261211-01   75   54  2.6232731-01  7.3400134-01
 76   54  2.5350197-01  7.4580934-01   77   55  2.4497354-01  7.5805048-01   78   58  2.3673203-01  7.6303571-01
 79   62  2.2876778-01  7.7644140-01   80   51  2.2107147-01  7.9079044-01   81   53  2.1363408-01  8.0612618-01
 82   57  2.0644691-01  8.2249555-01   83   50  1.9950152-01  8.3994913-01   84   50  1.9278980-01  8.5854153-01
 85   50  1.8630388-01  8.7833167-01   86   49  1.8003616-01  8.9938299-01   87   49  1.7397930-01  9.1823877-01
 88   49  1.6812620-01  9.4239281-01   89   49  1.6247003-01  9.6874891-01   90   49  1.5700413-01  9.9745522-01
 91   49  1.5172213-01  1.0286758+00   92   49  1.4661782-01  1.0625920+00   93   48  1.4168524-01  1.0994045+00
 94   48  1.3691860-01  1.1393349+00   95   48  1.3231232-01  1.1767322+00   96   48  1.2786101-01  1.2242898+00
 97   48  1.2355945-01  1.2765761+00   98   47  1.1940261-01  1.3340286+00   99   47  1.1538561-01  1.3971386+00
100   47  1.1150375-01  1.4664584+00  101   47  1.0775249-01  1.5426092+00  102   47  1.0412743-01  1.6245520+00
103   46  1.0062433-01  1.7172263+00  104   46  9.7239080-02  1.8197968+00  105   46  9.3967718-02  1.9333913+00
106   46  9.0806413-02  2.0592928+00  107   45  8.7751461-02  2.1989630+00  108   45  8.4799286-02  2.3595098+00
109   45  8.1946429-02  2.5306560+00  110   45  7.9189549-02  2.7198245+00  111   44  7.6525418-02  2.9291739+00
112   44  7.3950915-02  3.1611554+00  113   44  7.1463024-02  3.4185584+00  114   43  6.9058832-02  3.7045600+00
115   43  6.6735523-02  4.0520784+00  116   43  6.4490375-02  4.4057364+00  117   43  6.2320760-02  4.7961707+00
118   43  6.0224137-02  5.2276468+00  119   43  5.8198049-02  5.7049688+00  120   43  5.6240123-02  6.2335542+00
121   43  5.4348067-02  6.8195186+00  122   43  5.2519664-02  7.4697679+00  123   43  5.0752773-02  8.1921132+00
124   43  4.9045325-02  8.9953959+00  125   43  4.7395320-02  1.0011631+01  126   43  4.5800825-02  1.1014054+01
127   43  4.4259972-02  1.2123294+01  128   43  4.2770958-02  1.3351349+01  129   43  4.1332038-02  1.4711626+01
130   43  3.9941526-02  1.6219119+01  131   43  3.8597795-02  1.7890604+01  132   43  3.7299270-02  1.9744844+01
133   43  3.6044430-02  2.1802861+01  134   43  3.4831807-02  2.4088200+01  135   43  3.3659979-02  2.6741153+01
136   43  3.2527575-02  2.9565497+01  137   43  3.1433267-02  3.2689699+01  138   43  3.0375775-02  3.6145761+01
139    0  2.4461552+00  2.8406635-01

** DISCONTINITIES **  INDEX-SWITCH-ENERGY-RATIO
  1   -1  2.4461552+00  1.0000000+00    2   21  2.4461552+00  9.5829836-01    3   33  9.9999922-01  9.7371142-01
  4  -10  4.1514364-01  9.7829092-01    5   71  3.3333325-01  9.6635754-01    6   71  2.9353863-02  9.6635754-01


INTEGRAL OVER SCATTERED MOMENTS
 0  0  3.4089314-07   1  1  0.0000000      2  0  3.4613248-07   2  2  0.0000000      3  1  0.0000000      3  3  0.0000000
 4  0  3.5126633-07   4  2  0.0000000      5  1  0.0000000      6  0  3.5629745-07
SOURCE ENERGY      2.44616  CROSS SECTION   8.1627786-06
```

```
DIRECT IS ADDED IN
 0  0  8.5036716-06   1  1  0.0000000     2  0  3.0670586-06   2  2  0.0000000     3  1  0.0000000     3  3  0.0000000
 4  0  1.9838220-06   4  2  0.0000000     5  1  0.0000000     6  0  1.5224086-06


 COMPLETE SINGLE SCATTER SOURCE ---CCNL---
 0  0  5.9871023-05   1  1  1.9957008-05   2  0  6.9829955-05   2  2  7.9828030-06   3  1  2.8598520-05   3  3  3.4212013-06
 4  0  1.0310232-04   4  2  1.3492129-05   5  1  4.3362193-05   6  0  1.7541259-04
   *******  1.97691377+00
   *******  1.89447321+00
   *******  1.81547056+00
   *******  1.73976246+00
   *******  1.66721150+00
   *******  1.59768605+00
   *******  1.53105992+00
   *******  1.46721222+00
   *******  1.40602705+00
   *******  1.34739341+00
   *******  1.29120488+00
   *******  1.23735952+00
   *******  1.18575960+00
   *******  1.13631149+00
   *******  1.08892544+00
   *******  1.04351546+00
   *******  9.99999151-01
   *******  9.73710656-01
   *******  9.48113188-01
   *******  9.23188642-01
   *******  8.98919322-01
   *******  8.75288010-01
   *******  8.52277927-01
   *******  8.29872750-01
   *******  8.08056571-01
   *******  7.86613907-01
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   *******  7.07282774-01
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*******   9.08064125-02
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*******   7.14630242-02
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          *******  6.67355228-02
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          *******  5.25196642-02
          *******  5.07527734-02
          *******  4.90453253-02
          *******  4.73953197-02
          *******  4.58008246-02
          *******  4.42599724-02
          *******  4.27709580-02
          *******  4.13320377-02
          *******  3.99415260-02
          *******  3.85977947-02
          *******  3.72992698-02
          *******  3.60444305-02
          *******  3.48318070-02
          *******  3.36599792-02
          *******  3.25275748-02
          *******  3.14332671-02
          *******  3.03757747-02
 $KKK
 LZRO     =                 +0,
 MZRO     =                 +0,
 NNL      =                +10,
 NENS     =               +138,
 NSORS    =                 +1,
 IOUT     =                 +1,
 L1       =               +200,
 L2       =               +121,
 NDOSE    =                +33,
 NOFD     =                 +2,
 NENSPP   =               +139,
 IS       =                 +1,
 $END
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DOSE RESPONSE FUNCTIONS

ENERGY      DOSE( 1)     DOSE( 2)      DOSE(
100.0000   2.28000-02   1.62000-02
 80.0000   2.20400-02   1.57000-02
 60.0000   2.10300-02   1.52000-02
 50.0000   2.04200-02   1.49000-02
 40.0000   1.96600-02   1.45000-02
 30.0000   1.88100-02   1.43000-02
 20.0000   1.78800-02   1.41000-02
 15.0000   1.74900-02   1.43000-02
 10.0000   1.74100-02   1.51000-02
  8.0000   1.76400-02   1.57000-02
  6.0000   1.82700-02   1.68000-02
  5.0000   1.88600-02   1.78000-02
  4.0000   1.97700-02   1.89000-02
  3.0000   2.12400-02   2.07000-02
  2.0000   2.37600-02   2.36000-02
  1.5000   2.57700-02   2.57000-02
  1.0000   2.80600-02   2.80000-02
   .8000   2.90100-02   2.89000-02
   .6000   2.97400-02   2.96000-02
   .5000   2.99300-02   2.97000-02
   .4000   2.98800-02   2.95000-02
   .3000   2.94700-02   2.88000-02
   .2000   2.90600-02   2.68000-02
   .1500   3.04700-02   2.50000-02
   .1000   4.24300-02   2.34000-02
   .0800   6.27600-02   2.43000-02
   .0600   1.24400-01   3.05000-02
   .0500   2.05300-01   4.06000-02
   .0400   3.96100-01   6.69000-02
   .0300   9.47300-01   1.48000-01
   .0200   3.26600+00   5.11000-01
   .0150   7.82600+00   1.27000+00
   .0100   2.62700+01   4.61000+00

 NORMALIZED FLUX TO DOSE CONVERSION FACTORS
195.6924   1.13770-01   8.10194-02
156.5539   1.09977-01   7.85188-02
117.4155   1.04938-01   7.60182-02
 97.8462   1.01894-01   7.45179-02
 78.2770   9.81014-02   7.25174-02
 58.7077   9.38600-02   7.15172-02
 39.1385   8.92194-02   7.05169-02
 29.3539   8.72733-02   7.15172-02
 19.5692   8.68742-02   7.55181-02
 15.6554   8.80218-02   7.85188-02
 11.7415   9.11655-02   8.40202-02
  9.7846   9.41095-02   8.90214-02
  7.8277   9.86503-02   9.45227-02
  5.8708   1.05985-01   1.03525-01
  3.9138   1.18560-01   1.18028-01
  2.9354   1.28590-01   1.28531-01
  1.9569   1.40017-01   1.40034-01
  1.5655   1.44757-01   1.44535-01
  1.1742   1.48400-01   1.48036-01
   .9785   1.49348-01   1.48536-01
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.7828  1.49098-01  1.47535-01
.5871  1.47052-01  1.44035-01
.3914  1.45006-01  1.34032-01
.2935  1.52042-01  1.25030-01
.1957  2.11721-01  1.17028-01
.1566  3.13166-01  1.21529-01
.1174  6.20744-01  1.52537-01
.0978  1.02443+00  2.03049-01
.0783  1.97650+00  3.34580-01
.0587  4.72693+00  7.40178-01
.0391  1.62970+01  2.55561+00
.0294  3.90510+01  6.35152+00
.0196  1.31085+02  2.30555+01
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DIRECT RADIATION MOMENTS      EO =    1.25 MEV  CONCRETE    5-15-72

ENERGY     2.446155+00  SIGMA     2.840663-01 INDEX  139 LZRO    0 MZRO    0
 0  0  2.4461552+00   1  1  8.1538507-01   2  0  8.1538507-01   2  2  3.2615402-01   3  1  4.8923103-01   3  3  1.3978029-01
 4  0  4.8923103-01   4  2  2.7956058-01   5  1  3.4945073-01   6  0  3.4945073-01

ENERGY     9.999992-01  SIGMA     4.317041-01 INDEX  140 LZPO    0 MZRO    0
 0  0  3.9413426-05   1  1  8.6486989-06   2  0  1.9921634-05   2  2  2.2773963-06   3  1  5.3709933-06   3  3  6.4252448-07
 4  0  1.2746981-05   4  2  1.6680896-06   5  1  3.5292139-06   6  0  9.5984310-06
  .24461552+01    .13417606+00    .10793380+01    .00000000       .00000000
  .23441465+01    .13533820+00    .10413379+01    .50299668-02    .50326950-02
  .22463917+01    .13650518+00    .10081437+01    .23793102-01    .23804011-01
  .21527135+01    .13763394+00    .97814409+00    .32571913-01    .32586724-01
  .20629418+01    .13872337+00    .95115636+00    .49031662-01    .49053092-01
  .19769138+01    .13977239+00    .92696774+00    .56761441-01    .56785256-01
  .18944732+01    .14077996+00    .90539223+00    .71308739-01    .71334933-01
  .18154706+01    .14174508+00    .88628805+00    .78165906-01    .78191876-01
  .17397625+01    .14271339+00    .86939701+00    .91119213-01    .91141564-01
  .16672115+01    .14358219+00    .85483915+00    .97249085-01    .97266193-01
  .15976861+01    .14439182+00    .84240381+00    .10850799+00    .10851212+00
  .15310599+01    .14514123+00    .83200587+00    .11575122+00    .11574507+00
  .14672122+01    .14582943+00    .82356164+00    .12264229+00    .12262474+00
  .14060270+01    .14645552+00    .81701387+00    .13233744+00    .13230183+00
  .13473934+01    .14697769+00    .81242274+00    .13711502+00    .13706966+00
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  .12373595+01    .14792861+00    .80836543+00    .15063031+00    .15056469+00
  .11857596+01    .14831796+00    .80895709+00    .15903389+00    .15895197+00
  .11363115+01    .14864926+00    .81129231+00    .16307401+00    .16298261+00
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  .10435155+01    .14913072+00    .82125268+00    .17461185+00    .17448526+00
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  .99999922+00    .14928876+00    .82897829+00    .18362747+00    .18346107+00
  .97371066+00    .14935886+00    .83469493+00    .18472644+00    .18455452+00
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  .89891932+00    .14943615+00    .85636760+00    .19531172+00    .19507567+00
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  .80805657+00    .14920575+00    .89664332+00    .20724707+00    .20691402+00
  .78681391+00    .14911726+00    .90887391+00    .20916704+00    .20881553+00
  .76612969+00    .14901204+00    .92204558+00    .21295479+00    .21256412+00
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  .72637822+00    .14875156+00    .95139048+00    .21851785+00    .21806254+00
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.93967718-01   .11498757+01   .15656184+00   .36521494+00   .32785741+00
.90806413-01   .12695231+01   .11623528+00   .36598682+00   .32800482+00
.87751461-01   .14032195+01   .83849670-01   .36629253+00   .32806156+00
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.81946429-01   .17246744+01   .39536236-01   .36693988+00   .32817803+00
.79189549-01   .19093795+01   .25818126-01   .36719483+00   .32822230+00
.76525418-01   .21146975+01   .16239079-01   .36728389+00   .32823747+00
.73950915-01   .23430149+01   .98047814-02   .36740380+00   .32825754+00
.71463024-01   .25970042+01   .56763781-02   .36744256+00   .32826392+00
.69058832-01   .28796593+01   .31416843-02   .36749062+00   .32827174+00
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.56240123-01   .53863640+01   .29208720-04   .36753158+00   .32827829+00
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.44259972-01   .11204785+02   .49149423-08   .36753198+00   .32827835+00
.42770958-01   .12436820+02   .10044075-08   .36753198+00   .32827835+00
.41332038-01   .13803629+02   .18650075-09   .36753198+00   .32827835+00
.39941526-01   .15319881+02   .30627684-10   .36753198+00   .32827835+00
.38597795-01   .17001831+02   .43710830-11   .36753198+00   .32827835+00
.37299270-01   .18867490+02   .52493753-12   .36753198+00   .32827835+00
.36044430-01   .20936822+02   .49875703-13   .36753198+00   .32827835+00
.34831807-01   .23231943+02   .31217594-14   .36753198+00   .32827835+00
.33659979-01   .25805138+02   .28287600-17   .36753198+00   .32827835+00
.32527575-01   .28628591+02  -.29403086-16   .36753198+00   .32827835+00
.31433267-01   .31755493+02  -.41189946-17   .36753198+00   .32827835+00
.30375775-01   .35217847+02  -.28287681-18   .36753198+00   .32827835+00

NORMALIZING CONSTANT          1.43847384+00
```

```
EO =   1.25 MEV   CONCRETE     5-19-72

PLANE DOSE RATE INTEGRALS FOR THE  1 RESPONSE

TOTAL DOSE
 0  0  1.0008229+00   1  1  3.8984279-01   2  0  7.8751358-01   2  2  1.0688574-01   3  1  4.0603958-01   3  3  7.2167781-02
 4  0  8.0736414-01   4  2  2.1352197-01   5  1  4.3274310-01   6  0  8.5399975-01

DIRECT DOSE CONTRIBUTION
 0  0  4.7213783-01   1  1  1.5737831-01   2  0  1.5738073-01   2  2  6.2951070-02   3  1  9.4427023-02   3  3  2.6978958-02
 4  0  9.4428507-02   4  2  5.3957997-02   5  1  6.7447807-02   6  0  6.7449067-02

SCATTERED DOSE CONTRIBUTION
 0  0  5.2868514-01   1  1  2.3246448-01   2  0  6.3013286-01   2  2  1.0393468-01   3  1  3.1161255-01   3  3  4.5188824-02
 4  0  7.1293554-01   4  2  1.5956397-01   5  1  3.6529530-01   6  0  7.8655069-01
```

```
EO =   1.25 MEV  CONCRETE    5-15-72

PLANE DOSE RATE INTEGRALS FOR THE  2 RESPONSE

TOTAL DOSE
 0  0  9.4461367-01   1  1  3.8428069-01   2  0  7.1263745-01   2  2  1.6600353-01   3  1  3.9841955-01   3  3  7.2033465-02
 4  0  7.2038832-01   4  2  2.1225992-01   5  1  4.2381782-01   6  0  7.5673150-01

DIRECT DOSE CONTRIBUTION
 0  0  4.7239387-01   1  1  1.5746366-01   2  0  1.5746607-01   2  2  6.2985212-02   3  1  9.4478235-02   3  3  2.6993591-02
 4  0  9.4479811-02   4  2  5.3987263-02   5  1  6.7484385-02   6  0  6.7485640-02

SCATTERED DOSE CONTRIBUTION
 0  0  4.7221981-01   1  1  2.2681702-01   2  0  5.5517139-01   2  2  1.0301832-01   3  1  3.0394132-01   3  3  4.5039875-02
 4  0  6.2590850-01   4  2  1.5827266-01   5  1  3.5633344-01   6  0  6.8924588-01
 EO =   1.25 MEV  CONCRETF    5-15-72

 POINT DOSE RATE INTEGRALS FOR THF  1 RESPONSF

TOTAL DOSE
 0  0  1.0008229+00   1  1  1.1695284+00   2  0  2.3625408+00   2  2  1.2516431+00   3  1  2.0301979+00   3  3  1.2629362+00
 4  0  4.0366208+00   4  2  1.8683173+00   5  1  3.0292018+00   6  0  5.9779985+00

DIRECT DOSE CONTRIBUTION
 0  0  4.7213783-01   1  1  4.7213494-01   2  0  4.7214220-01   2  2  4.7213303-01   3  1  4.7213512-01   3  3  4.7213177-01
 4  0  4.7214305-01   4  2  4.7213249-01   5  1  4.7213467-01   6  0  4.7214349-01

SCATTERED DOSE CONTRIBUTION
 0  0  5.2868514-01   1  1  6.9739343-01   2  0  1.8903986+00   2  2  7.7951007-01   3  1  1.5580628+00   3  3  7.9080444-01
 4  0  3.5646778+00   4  2  1.3961848+00   5  1  2.5570672+00   6  0  5.5058550+00
```

```
EO =   1.25 MEV  CONCRETE    5-15-72

POINT DOSE RATE INTEGRALS FOR THE  2 RESPONSE

TOTAL DOSE
 0  0  9.4461367-01   1  1  1.1528421+00   2  0  2.1379124+00   2  2  1.2450265+00   3  1  1.9920978+00   3  3  1.2605857+00
 4  0  3.6019416+00   4  2  1.8572744+00   5  1  2.9667249+00   6  0  5.2971207+00

DIRECT DOSE CONTRIBUTION
 0  0  4.7239387-01   1  1  4.7239099-01   2  0  4.7239822-01   2  2  4.7238909-01   3  1  4.7239118-01   3  3  4.7238785-01
 4  0  4.7239907-01   4  2  4.7238857-01   5  1  4.7239072-01   6  0  4.7239950-01

SCATTERED DOSE CONTRIBUTION
 0  0  4.7221981-01   1  1  6.8045107-01   2  0  1.6655142+00   2  2  7.7263740-01   3  1  1.5197066+00   3  3  7.8819783-01
 4  0  3.1295426+00   4  2  1.3848858+00   5  1  2.4943342+00   6  0  4.8247213+00
```

REFERENCES

[1] U. Fano, L. V. Spencer, and M. J. Berger, "Penetration and Diffusion of X-rays," Handbuch der Physik, XXXVIII (Springer-Verlag, Berlin, 1959).

[2] L. V. Spencer, "Plural Series Representation of Functions, J. Res. Nat. Bur. Standards (to be published).

[3] L. V. Spencer and U. Fano, "Penetration and Diffusion of X-Rays. Calculation of the Spatial Distributions by Polynomial Expansion," J. Res. Nat. Bur. Standards 46, 446 (1951).

[4] H. Goldstein and J. Ernest Wilkins, Jr., "Calculations of the Penetration of Gamma Rays," AEC Report NYO-3075, June 30, 1954.

[5] L. V. Spencer and J. C. Lamkin (unpublished).

[6] L. V. Spencer and J. C. Lamkin, "Slant Penetration of γ-Rays in H_2O," NBS Report 5944, unpublished.

[7] L. V. Spencer and J. C. Lamkin, "Slant Penetration of γ-Rays: Mixed Radiation Sources," NBS Report 6322, unpublished.

[8] L. V. Spencer and J. C. Lamkin, "Slant Penetration of γ-Rays in Concrete," NBS Report 6591, unpublished.

[9] L. V. Spencer, "Structure Shielding Against Fallout Radiation from Nuclear Weapons," NBS Monograph 42, U.S. Gov't Printing Office, June, 1962.

[10] C. Eisenhauer, "An Engineering Method for Calculating Protection Afforded by Structures Against Fallout Radiation," NBS Monograph 76, U.S. Gov't Printing Office, July, 1964.

[11] "Design and Review of Structure for Protection from Fallout Gamma Radiation," PM-100-1, Office of Civil Defense, Feb., 1965.

[12] E. T. Bramlitt and C. M. Eisenhauer, "A Discussion and Tabulation of the OCD Standard Method for Fallout Gamma Radiation Shielding Analysis," TR-70, Office of Civil Defense, December, 1971.

[13] "Shelter Design and Analysis, Volume 1, Office of Civil Defense, June, 1968 (Rev: 1969, 1970, 1971).

[14] C. Eisenhauer, G. L. Simmons and L. V. Spencer, "A Neutron Moments Computer Code, Moment I.," NBS Technical Note 725, June, 1972.

U. S. GOVERNMENT PRINTING OFFICE · 1973—511-324/216

FORM NBS-114A (1-71)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET**	1. PUBLICATION OR REPORT NO. NBS TN-766	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

A Gamma Ray Moments Computer Code. GAMMØM-I

5. Publication Date
April 1973

6. Performing Organization Code

7. AUTHOR(S)
Charles M. Eisenhauer, George L. Simmons, and Lewis V. Spencer

8. Performing Organization

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No.
2400434 - 2400439

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

Defense Civil Preparedness Agency, Washington, D.C. 20310
Office of Naval Research, Arlington, Va. 22217

13. Type of Report & Period Covered
Final

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

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In this paper we describe a computer code for generating spatial-angular moments of gamma ray energy fluence in an infinite medium. The equation for moments of the energy fluence is given and the techniques used for the solution are discussed. The structure of the code and of the main subroutines is also given. Details of the input and output data are presented and the printout from a sample problem is included.

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